Synthetic Aperture Metrology

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1. Synthetic Aperture Metrology

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Introduction

We have developed a new optical paradigm for semiconductor critical dimension (CD) metrology, which we call Synthetic Aperture Metrology (SAM). SAM combines the speed of optical methods with the microscope imaging capability of CD scanning electron microscopy (CD-SEM). Its accuracy derives from the interference of multiple coherent laser beams. Its imaging property means that it can be used to determine CDs of arbitrary structures–not just specially-designed, periodic, metrology pads, but also CDs of designed parts such as gate widths. Since it does not require moving parts or a vacuum, SAM can be fast relative to other CD metrology tools. We propose to develop a method for measuring linewidths (>50 nm) in less than 10 milliseconds, which represents a 300-fold speedup relative to the fastest published optical method.

The goal of the SAM project is to develop a method for critical dimension (CD) metrology that is:

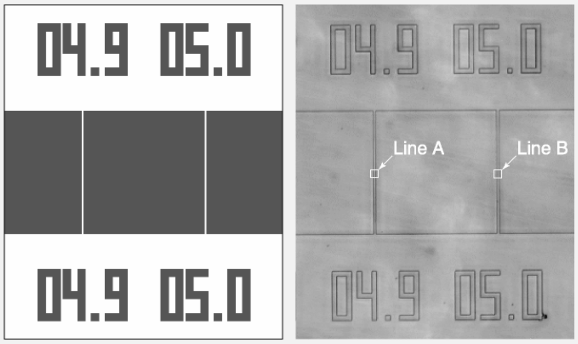
1. optical and non-contact (like a scatterometer), but also has the microscope imaging benefits of CD-SEM,

2. fast, in two ways:
    a. SAM requires no moving parts, unlike a scatterometer, and can collect data approximately equivalent to scatterometer points at the 20-80 MHz rate,
    b. SAM data reduction is a forward problem (not an inverse problem as in scatterometric CD measurement, which requires the expensive precomputation of a “library” of possible unknown structures),

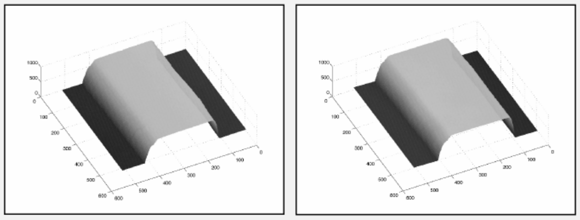
3. applicable to non-periodic structures (such as single gates) in resist as well as post-etch materials.

Measurements of Lines Patterned in Resist

The widths of isolated 5-μm-wide lines were measured with an experimentally determined 3-σ uncertainty of 0.058 μm (1% of the linewidth). The top-left panel of Figure 1 shows a region of the photomask used to generate lines of varying widths. The two shown vertical lines, which will be referred to as line A and line B, are 4.9 μm and 5.0 μm wide on the photomask. The entire photomask contains 3200 similar lines. In previous experiments, Shipley S1805 was found to be a suitable candidate fluorescent photoresist for SAM development. Subsequent testing determined that the fluorescent properties of S1805 (i.e., fluorescent intensity with 488-nm excitation and photobleaching rate) are not significantly affected with standard photolithographic processing. The top-right panel of Figure 1 shows the corresponding patterns in resist. The size of the field of view is approximately 500 μm x 750 μm.



Photomask **Resist pattern**



AFM (Line A) **AFM (Line B)**

Figure 1: Lines of varying widths patterned in resist.

The bottom panels of Figure 1 show atomic force microscope (AFM) measurements of the two lines patterned in resist. The white boxes in the top-right panel indicate the approximate locations of the AFM measurements. Measurements were made using a tapping-mode AFM (Multimode, Digital Instruments) using rotated etched silicon probe (RTESP, Veeco). The estimated widths of line A and line B were 5.57 μm and 5.75 μm, respectively.

Figure 2 illustrates the experimental procedure used to perform SAM linewidth measurements. Two laser beams split from a 488-nm single-frequency argon ion laser (I-304C, Coherent) were used to illuminate the resist pattern. The two beams were transverse electric (TE, or S) polarized and approximately 0.41 mW and 0.46 mW in intensity. The interference of the two beams created a fringe pattern with a period of 1.17 mm and a fringe visibility of 0.93. The spatial phase of the interference pattern could be modulated by shifting the phase of the laser beams using piezoelectric actuators. Light fluoresced by the resist pattern was collected using a 10x/0.25NA objective lens and detected using a photon-counting PMT module (H8259-01, Hamamatsu). Scattered laser light was rejected with a glass longpass filter (3-mm-thick OG-515, Schott).

Figure 3 shows typical raw SAM data obtained in two linewidth measurements. Each linewidth measurement consisted of eight light-intensity measurements, each with the interference pattern at a different spatial phase. For each light-intensity measurement, the PMT was allowed collect light for 12 ms. Approximately 1000 photons were detected in each 12 ms interval. Light was collected for a total of 96 ms for each linewidth measurement. The raw SAM data was least-squares fit to an offset sinusoid to produce a robust estimate of Fourier amplitude for each linewidth measurement.

Figure 4 shows estimated Fourier amplitudes from 200 linewidth measurements of line A and line B. The widths of the lines were each measured 100 times. To reduce the possibility of manual-alignment or time-dependent factors biasing the linewidth measurements, data was collected in alternating sets of 25 linewidth measurements. The experimental apparatus was realigned between each set of 25 measurements. As seen in Figure 4, the measured Fourier amplitude of line A was approximately twice the measured Fourier amplitude of line B.

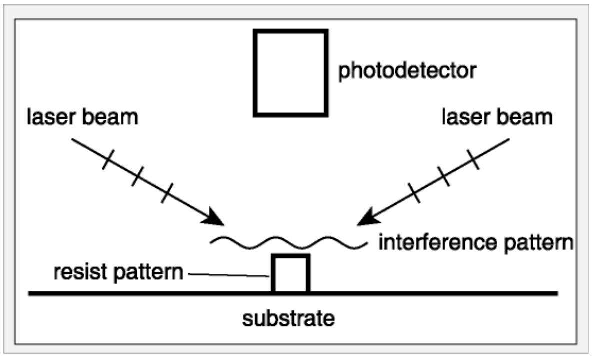


Figure 2: Schematic diagram of experimental procedure.

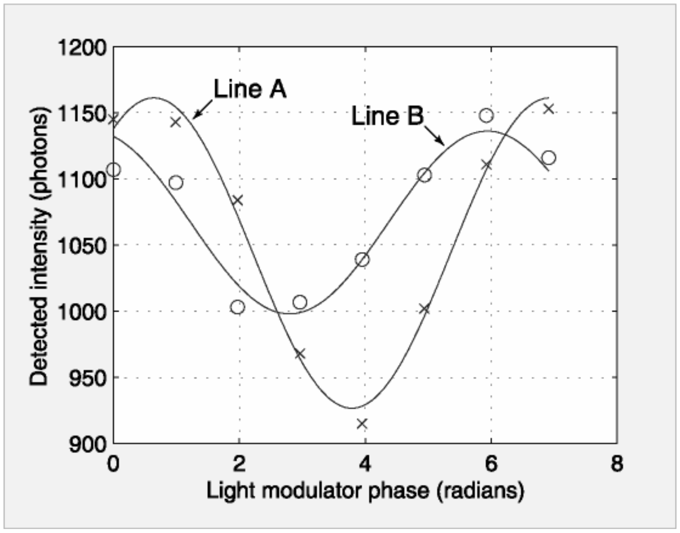


Figure 3: Typical raw SAM data.

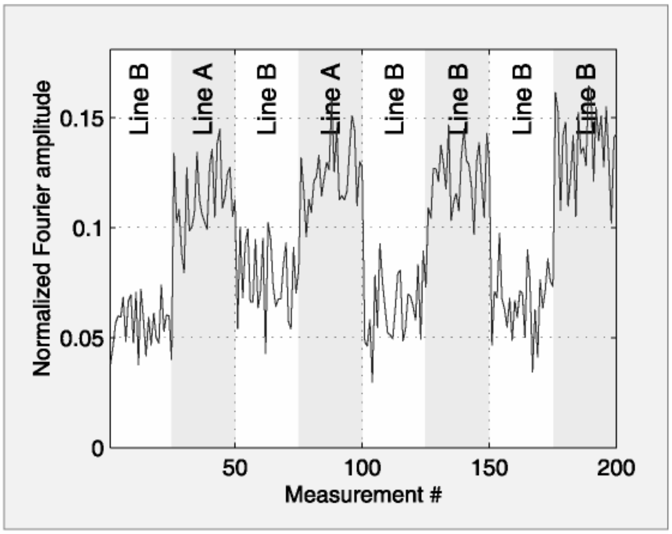


Figure 4: Estimated Fourier amplitudes from raw SAM data.

Figure 5 shows the estimated widths of line A and line B determined from the 200 Fourier amplitude measurements shown in Figure 4. The mean estimated linewidth of line A was 5.73 μm with a standard deviation of 0.0206 μm. The mean estimated linewidth of line B was 5.80 μm with a standard deviation of 0.0179 μm. A difference in linewidth of 0.070 μm was readily detected. The 3-σ uncertainty of the measurements was approximately 0.058 μm (1.0% of the linewidth).

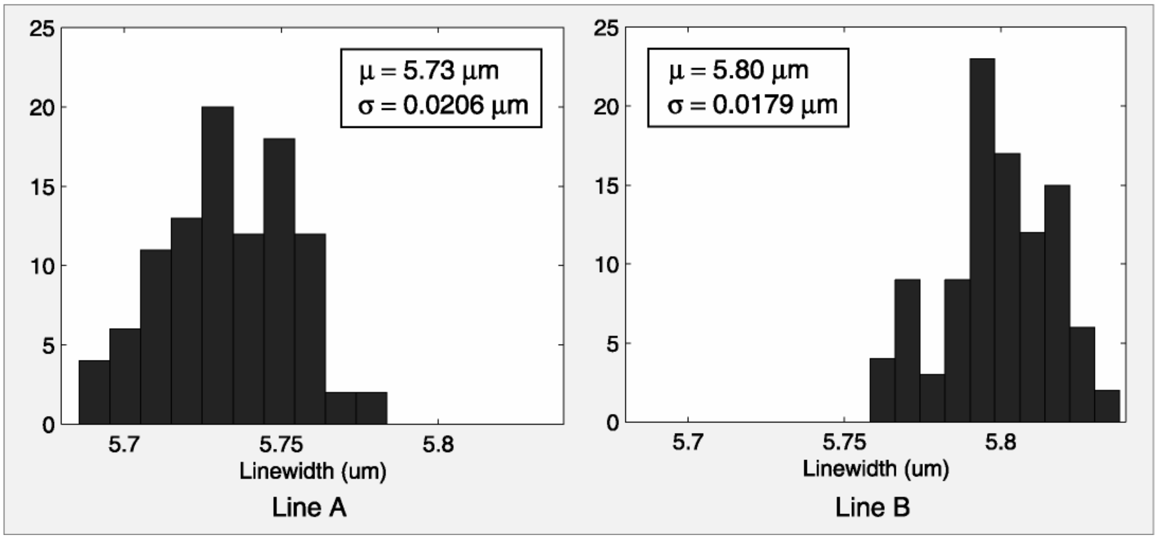


Figure 5: Estimated linewidths measured with SAM.

Journal Articles, Accepted for Publication

S. S. Hong, M. S. Mermelstein, and D. M. Freeman, "Reflective Acousto-optic Modulation with Surface Acoustic Waves," *Applied Optics* (in press).

Meeting Papers, Published

J. Ryu, B.K.P. Horn, M. S. Mermelstein, S. S. Hong, and D. M. Freeman, "Application of Structured Illumination in Nano-scale Vision", *IEEE Workshop on Computer Vision for the Nano-Scale*, 2003.

Theses

Ryu, J., *Resolution Improvement in Optical Microscopy by Use of Multi-Beam Interferometric Illumination*, Ph.D. diss., M.I.T., September 2003.